OPERATION AND MAINTENANCE COSTS FOR MUNICIPAL WASTEWATER TREATMENT FACILITIES IN CANADA

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by

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ABSTRACT

Operating and maintenance cost data were collected at 52 Municipal Wastewater Treatment Facilities in Canada in 1981. Facilities surveyed included primary treatment plants, secondary treatment plants and aerated and facultative lagoon systems. Cost data presented in this report are in 1980 dollars.

RÉSUMÉ

En 1981 au Canada, on a recueilli des données sur les coûts d'opération de 52 usines d'épuration des eaux usées. Ces usines étaient de type primaire, secondaire, étang aéré, ou étang facultatif. Les coûts d'opération présentés dans ce rapport sont pour l'année 1980.

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1 INTRODUCTION

The success or failure of a municipal wastewater treatment plant to perform as desired is dependent upon three important factors:

1) planning and design;
2) construction; and
3) operation and maintenance.

If any one of these factors is inadequately or improperly performed, it is unlikely that the facility will provide satisfactory results. While a significant effort is put forward during the planning, designing and construction stage of a project to meet budget estimates on capital items and provide a useful end product, the same is not always true for operation and maintenance (O & M) of the facility. Rough estimates of personnel and budget needs are made during project planning, but the O & M funding commitment to sewage treatment often is not fully appreciated until a facility has been operating for a period of time.

With the provision of O & M costs data from a national data base, assistance would be available to predict budget requirements for municipal wastewater treatment facilities. To initiate the development of such a data base, a 1981 national survey was conducted. Data were collected from 52 municipal wastewater facilities in various regions of Canada on the basis of 1980 O & M records and dollar values. This report summarizes information collected during that national survey. To improve upon the accuracy or to update these data, more intensive review of facilities of a specific process-type or size group will be required. Comprehensive coverage of this nature should occur as needs are identified.

1.1 Background

In Canada, municipal sewage is discharged to sanitary collectors at a rate of approximately 11 x 10^6 m^3/d. About 55% (6 x 10^6 m^3/d) of this wastewater receives some form of treatment. Treatment processes such as activated sludge, primary sedimentation, aerated lagoons and facultative lagoons account for approximately 90-95% of the processed wastewater: 60% by activated sludge; 20% by primary treatment; 6% by aerated lagoons; and 5-10% by facultative lagoons.

At present there are approximately 450 activated sludge plants, (or modified versions of activated sludge), 74 primary plants, and 746 aerated or facultative lagoons

operating in Canada. The majority of the mechanical plants, (ie. activated sludge and primary plants), have capacities of 50 000 m^3/d or less. Between 85-90% of facultative and aerated lagoons have design capacities that are less than 10 000 m^3/d.

During the summer of 1981, a survey of 52 municipal wastewater treatment facilities was completed by an engineering consultant under contract to EPS. The survey included the examination of 1980 operational records at various facilities across the country including: 25 conventional activated sludge plants; 9 primary plants; 8 aerated lagoon systems; and 10 facultative lagoon systems. Seven activated sludge plants, three primary plants, one aerated lagoon and two facultative lagoons included in the survey contained phosphorus-removal processes.

1.2 Objectives

The specific objectives of the project included:

1) To collect O & M cost information at selected sewage treatment facilities;
2) To develop an O & M cost information resource manual;
3) To examine the significant components of O & M costs at sewage treatment plants;
4) To develop relationships between O & M costs and common sewage treatment parameters such as average daily flow and pollutant removal rates for various types of facilities.

2 SURVEY METHODOLOGY

Data presented in this report were obtained during site visits to sewage treatment plants in various regions of Canada. For the purpose of this survey, regions were defined as follows:

Western: British Columbia, Alberta, Saskatchewan, Manitoba

Central: Ontario

Eastern: Quebec, New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland.

Interviews were held with responsible individuals associated with the 52 plants surveyed. Data on the facility and its operation and maintenance costs were obtained from 1980 records, whenever possible. In some situations it was necessary to use pre-1980 information and update to a common dollar value (1980 dollars) using standard indexing techniques.

The plants in each region were selected on the basis of process-type and size. The types of plants considered were categorized as:

	Levels	Process-type
1.	Primary Treatment	Primary clarification
2.	Secondary Treatment	Conventional Activated Sludge
		Extended Aeration
		Contact Stabilization
		Step Aeration
3.	Lagoons	Aerated
		Facultative

Primary treatment will typically remove about 60 percent of the raw sewage SS and about 35 percent of the BOD. Of the primary facilities surveyed SS removal efficiencies ranged from 55% to 89% (average 72%) and BOD removal efficiencies from 35% to 70% (average 52%). Secondary treatment processes are designed to remove 85% to 90% BOD and SS. For the 25 plants surveyed BOD removals varied from 70% to 97% (87% average) and SS removal efficiencies ranged from 65% to 95% (88% average). Wide variations in removal efficiencies were experienced in the lagoon systems survey. BOD and SS removal rates varied from 66% to 97% and 19% to 93% respectively for aerated lagoons, and from 41% to 98% and 22% to 95% respectively for facultative lagoons.

In addition to treatment levels, plants were selected and grouped according to size. Size categories included:

1.	Small	< 1000 m^3/d and 1000-5000 m^3/d
2.	Medium	5000-50 000 m^3/d
3.	Large	> 50 000 m^3/d

Seven of the 52 plants surveyed were in the large category; i.e. 5 secondary and 2 primary systems. Twenty-two plants in the survey were of the small variety; i.e. 10 lagoons; 2 primary; and 8 secondary systems; while 5 primary , 13 secondary and 5 lagoon systems were in the 5000 to 50 000 m^3/d category.

General information on the surveyed plants is included in Appendix A of this report.

3 DATA ANALYSIS

Data manipulation was completed on the basis of four considerations:

1) plant-type;
2) operational capacity;
3) component costs; and
4) pollutant removal

3.1 Plant-type

Data was initially collated on the basis of level of treatment, ie primary, secondary, and lagoons. For secondary systems, a distinction was not made between the type of processes employed (ie. conventional activated sludge or modified versions). Lagoon systems were analyzed according to type of operation; ie aerated and facultative lagoon data were considered in separate analyses.

3.2 Operational Capacity

Cost data on plant-types were categorized on the basis of plant size, as outlined previously, and then analyzed according to operational capacity. Operational capacity was assessed on the basis of average daily flow versus design daily flow. A facility was considered to be design loaded if average daily flows were in the range of 90% to 110% of design flow. Treatment facilities with actual daily flows greater than 110% of the design flow were defined as overloaded. Underloaded plants were defined as those plants with average daily loading of less than 90% design flow.

3.3 Component Costs

Component costs are general budgetary categories which collectively make up the total O & M costs of municipal wastewater treatment facilities. The major component costs assessed in this investigation were:

1) Electrical: All expenditures for electrical power other than sewage pumping station requirements.
2) Personnel: Wages and fringe benefits for operating staff and supervisory personnel.
3) Chemicals: Costs for process chemicals including chlorine for disinfection and/or odour control, precipitant chemicals for phosphorus removal, and miscellaneous chemicals used around the plant, such as air sweeteners. Chemicals associated with sludge treatment are incorporated into sludge costs.

4) Sludge: Expenditures for digester heating, sludge dewatering chemicals, off-site haulage, contracts for disposal, and where applicable, incineration (fuel) costs.

5) Administration and Miscellaneous: Administrative and support activities related to the daily operation and maintenance of a plant. Other miscellaneous costs included are vehicle maintenance, municipal taxes, insurance premiums, outside service costs for materials and labour, outside laboratory costs and heating (fuel) costs. These costs were often inconsistent from plant to plant.

3.4 Pollutant Removal

Pollutant removal efficiencies were determined on the basis of annual average influent and effluent concentrations and average daily flows. Biochemical oxygen demand, suspended solids and phosphorus removals were calculated in terms of kg removed per day. This information was then used to analyze operational costs for plant-types according to pollutant removal rates.

3.5 Cost Updating Procedures

Cost data presented in this report are in 1980 Canadian dollars. To convert these costs to the present, cost indexes must be used. A cost index is simply a ratio of cost at a given time relative to a specified base time. Because the cost was known for the time these data were collected, then the index equivalent cost at the present time can be determined by using the following equation:

$$\text{PRESENT COST} = \text{ORIGINAL COST} \times \frac{\text{INDEX VALUE AT PRESENT TIME}}{\text{INDEX VALUE AT TIME ORIGINAL DATA WERE OBTAINED}}$$

$$\text{PRESENT COST} = \text{ORGINAL COST} \times \text{INDEX RATIO}$$

Several such cost indexes are published regularly. The US EPA prepares a quarterly operation, maintenance and repair index for American wastewater treatment facilities.(1) It is a very complete cost index that includes labour, chemical, power, maintenance, administration and other cost indexes. However, it reflects US price trends, and thus may not be completely satisfactory for updating Canadian cost data. Some Canadian cost indexes may be used for updating the O & M cost information. These include:

a) Electrical Costs In the Statistics Canada publication, Industry Price Indexes[2] a Non-Residential Electric Power Selling Price Index is presented. This index is determined monthly for each province, and on a national basis, and for two different electric demand categories (> 5000 kw and < 5000 kw).

b) Labor Costs In the Statistics Canada monthly publication, Employment, Earnings and Hours[3, 4], the results of a national wage survey for several activity sectors are presented. The activity sector No. 576 "Water Systems" appears to be the best estimate of salaries paid at sewage treatment plants.

Although these data are presented in the form of weekly salaries and not in a cost index form (dimensionless data with base year), current and historical data may be used to update wages and salaries in exactly the same manner as cost indexes.

c) Chemical Costs There are cost indexes for a few chemicals like chlorine and sodium hydroxide in the previously mentioned publication, Industry Price Indexes[2]. Another source of chemical cost data would be the Corpus Chemical Report[5], a weekly market letter on Canada's chemical process industries. It contains cost data on chlorine, aluminium sulfate, lime, methanol and several other chemicals. Again, these are not cost indexes but actual market prices, but they may be used in the same manner as cost indexes in the updating equation.

d) Sludge Costs The sludge costs reported in this document include the following costs:

* Sludge dewatering chemical costs
* Digester heating costs
* Incineration (fuel) costs
* Sludge haulage costs

It is difficult to determine an index that will appropriately describe the effect of inflation on all these costs. However, since all these costs (especially the last three) are effected by fuel costs, the fuel cost indexes in the Statistics Canada publication Industry Price Indexes[2] may be a good approximation.

e) Administrative and Miscellaneous Costs This is the most diverse cost category in the report, and thus the one for which appropriate cost index selection is most difficult. An average of the index ratios for the electrical, labour, chemical and sludge costs was considered a reasonable approximation for updating this cost group.

Example of cost updating. The following table represents the updating of the cost data for plant No. 26 from 1980 to 1983 (August). The equivalent total O & M cost for 1983 obtained is \$53.50 per 1000 m^3 of actual flow, an increase of about 25%.

If the US - EPA operation and maintenance index for wastewater treatment facilities is used instead, the equivalent total O & M cost for 1983 calculated is \$52.50 per 1000 m^3 of actual flow, an increase of 23%.

On the average, for all sewage treatment plants surveyed in this study, 1983 O & M costs were estimated to be 26% higher than those for 1980. These estimated 1983 O & M costs are plotted in Figures 1, 2, 3 and 4, along with the 1980 data in subsection 4.2.1.

TABLE 1 UPDATING OF COST DATA FOR PLANT No. 26: Activated Sludge Plant/Central Region

Component Cost	1980 Cost $/1000 m^3 Actual Flow	Index Used for Updating	Index Value Component			1983 Cost $/1000 m^3 Actual Flow
			1980 (Average) (1)	Aug 1983 (2)	Index Ratio (2)/(1)	
Electrical Costs	5.65	Stats. Canada Electric Power Selling Price Index . Prov: Ontario . Demand < 5000 KW	226.4	290.5	1.283	7.25
Personnel Costs	20.86	Stats. Canada Wage Survey . Activity Sector: Water Systems . Prov: Ontario . Data in $/week	464.3	482.6	1.039	21.67
Sludge Costs	7.25	Stats. Canada Fuel Cost Index	438.8	696.0	1.586	11.50
Chemical Costs	5.88	Stats. Canada Chlorine Cost Index	248.4	376.3	1.515	8.91
Additional Costs	3.10	Average Index Ratio	----	----	1.356	4.20
Total O & M Costs	42.75	----	----	----	----	53.53
Total O & M Costs	42.75	EPA - Operation Maintenance Repair Index for STP'S	2.94	3.61	1.228	52.30

4 SURVEY RESULTS AND FINDINGS

4.1 Regional Breakdown of Plants Surveyed

Table 2 illustrates the distribution of plants surveyed by region and according to plant size. The minimum number of plants surveyed in any one region was 14, in the Eastern region. Plants in the 5000 m^3/d to 50 000 m^3/d size range were visited more than any other group; the least surveyed size group was the group in the greater than 50 000 m^3/d category with only seven plant visits. It is also noted that seven of the plants surveyed in the Eastern region did not have actual daily flow information available.

The distribution of wastewater treatment plants surveyed by level of treatment is shown in Table 3. Secondary plants were visited more often than other facilities, followed by lagoons and primary plants. Phosphorus removal processes were included in 13 of the plants surveyed, 7 of which were secondary systems. Only one of the 13 surveyed plants was located outside of the Central region.

TABLE 2 NUMBER OF PLANTS SURVEYED BY REGION AND SIZE GROUPS

Plant Size (m^3/d)	Region			
	Eastern	Central	Western	Total
< 1000	-	4	1	5
1000 - 5000	1	6	4	11
5000 - 50 000	6	7	9	22
> 50 000	-	3	4	7
N/A*	7	-	-	7
Total	14	20	18	52

*Note: No information available on average daily flow.

4.2 Operational Capacity

4.2.1 Annual Hydraulic Loading. Table 4 presents average O & M costs according to level of treatment and plant size. Costs (1980) are on the basis of dollars per 1000 m^3 of wastewater treated.

Table 4 shows that the cost of treating wastewater increases as the level of treatment increases. Excluding all systems treating less than 1000 m^3/d from

TABLE 3 NUMBER OF PLANTS SURVEYED BY REGION AND LEVEL OF TREATMENT

Level of treatment*	Region			
	Eastern	Central	Western	Total
Primary	2	4(3)	3	9(3)
Secondary	6	10(6)	9(1)	25(7)
Aerated lagoons	3	3(1)	3	9(1)
Facultative lagoons	3	3(2)	3	9(2)
Total	14	20(12)	18(1)	52(13)

*Note: Numbers in brackets indicate plants with phosphorus removal.

TABLE 4 AVERAGE O & M COST PER 1000 m^3 TREATED** ($/1000 m^3)

Plant Size (m^3/d)	Level of Treatment			
	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	222 (n=2)	-	72 (n=3)
1000-5000	38 (n=2)	71 (n=4)	37 (n=3)	4 (n=1)
5000-50 000	49 (n=4)	58 (n=11)	26 (n=5)	2 (n=2)
> 50 000	41 (n=2)	27 (n=4)	-	-
All plants*	44 (n=8)	54 (n=19)	30 (n=8)	3 (n=3)

** Plants < 1000 m^3/d excluded.

n = number of plants included in calculation of averages.

** Average Cost/1000 m^3 = $\frac{\text{Total Annual Operation and Maintenance Costs}}{\text{Actual Flow (1000 } m^3\text{/d) x 365}}$

consideration, facultative lagoons average \$3/1000 m^3, aerated lagoons \$30, primary plants \$44, and secondary plants \$54. If the aforementioned small systems are considered in the averaging, the cost of operating surveyed facultative lagoons increases to \$32/1000 m^3, while secondary treatment costs balloon to \$104/1000 m^3. The former set of averages are probably more representative of average operational costs than the latter.

For all levels of treatment except primary, the average cost per 1000 m^3 of treated sewage decreases as the plant size increases. The exception among the primary plants surveyed was a plant treating greater than 50 000 m^3/d (\$55 per 1000 m^3). Phosphorus removal was being practiced at this particular plant. One other primary treatment facility in the same size category, but operating without phosphorus removal processes, was found to have an average O & M cost of \$27 per 1000 m^3 treated.

Figures 1, 2, 3, and 4 are graphical presentations of annual O & M costs versus average daily flows at primary, secondary, aerated lagoon and facultative lagoon facilities respectively. Generally, the figures illustrate that costs increase as the level of treatment progresses from lagoons, to primary, to secondary processes. Secondly, with the exception of primary plants, economies of scale are evident. As flow rates increase, annual operating costs per unit of flow decrease for secondary plants (Figure 2) and aerated lagoons (Figure 3). Figure 1 illustrates that as flows to primary plants increase, costs per unit flow increase.

4.2.2 Average Daily Flow versus Design Daily Flow. Table 5 summarizes data on the basis of average daily flow versus design daily flow. The data are presented to illustrate the hydraulic operating conditions at the plants surveyed. In this review, a plant is described as being underloaded with respect to flow capacity when the average daily flow is less than 90% of the design daily flow capacity of the plant (i.e. A/D < 0.9). With the exception of lagoons, the majority of the plants surveyed were reported as operating in an underloaded state. Twenty-two percent of the plants surveyed were operating within 90 to 110 percent of the design flow; seven of the 10 facilities in this category were secondary treatment plants. Twenty-two percent of the facilities were reported to have average daily flows exceeding the design requirements by more than 10 percent. Lagoons account for 60 percent of the plants in the overloaded operating condition.

The National Inventory of Municipal Waterworks and Wastewater Systems[6] contains inventory information on 74 primary plants, 454 activated sludge (or modified versions of the activated sludge process) systems, 140 aerated lagoons and 586 facultative lagoon facilities. A search of Mundat, the computer-based data management system for

FIGURE 1 – O & M COSTS (10^3 $/YEAR) VERSUS FLOW RATE FOR PRIMARY SEWAGE TREATMENT PLANTS

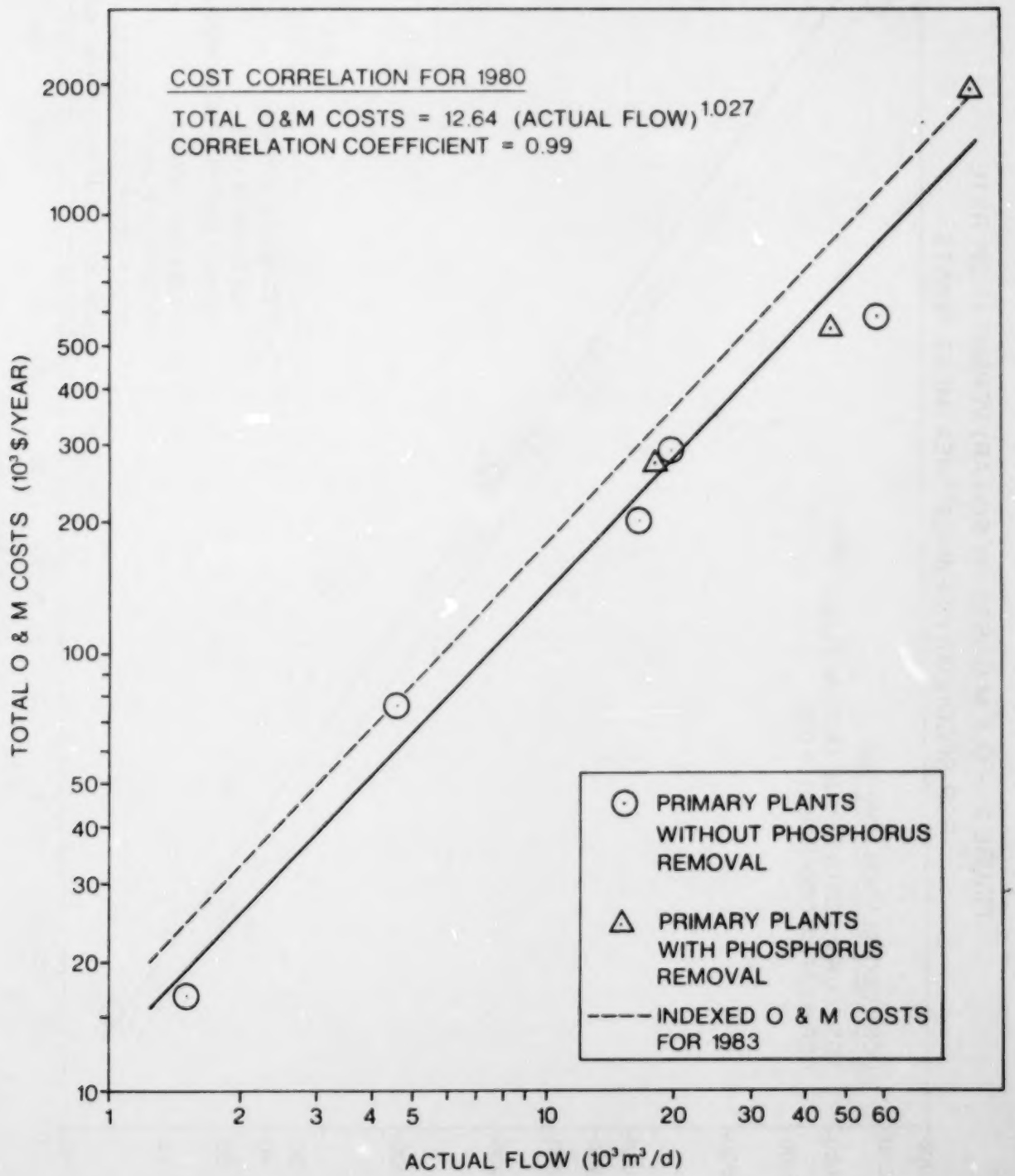

FIGURE 2 – O & M COSTS (10^3 $/YEAR) VERSUS FLOW RATE FOR SECONDARY SEWAGE TREATMENT PLANTS

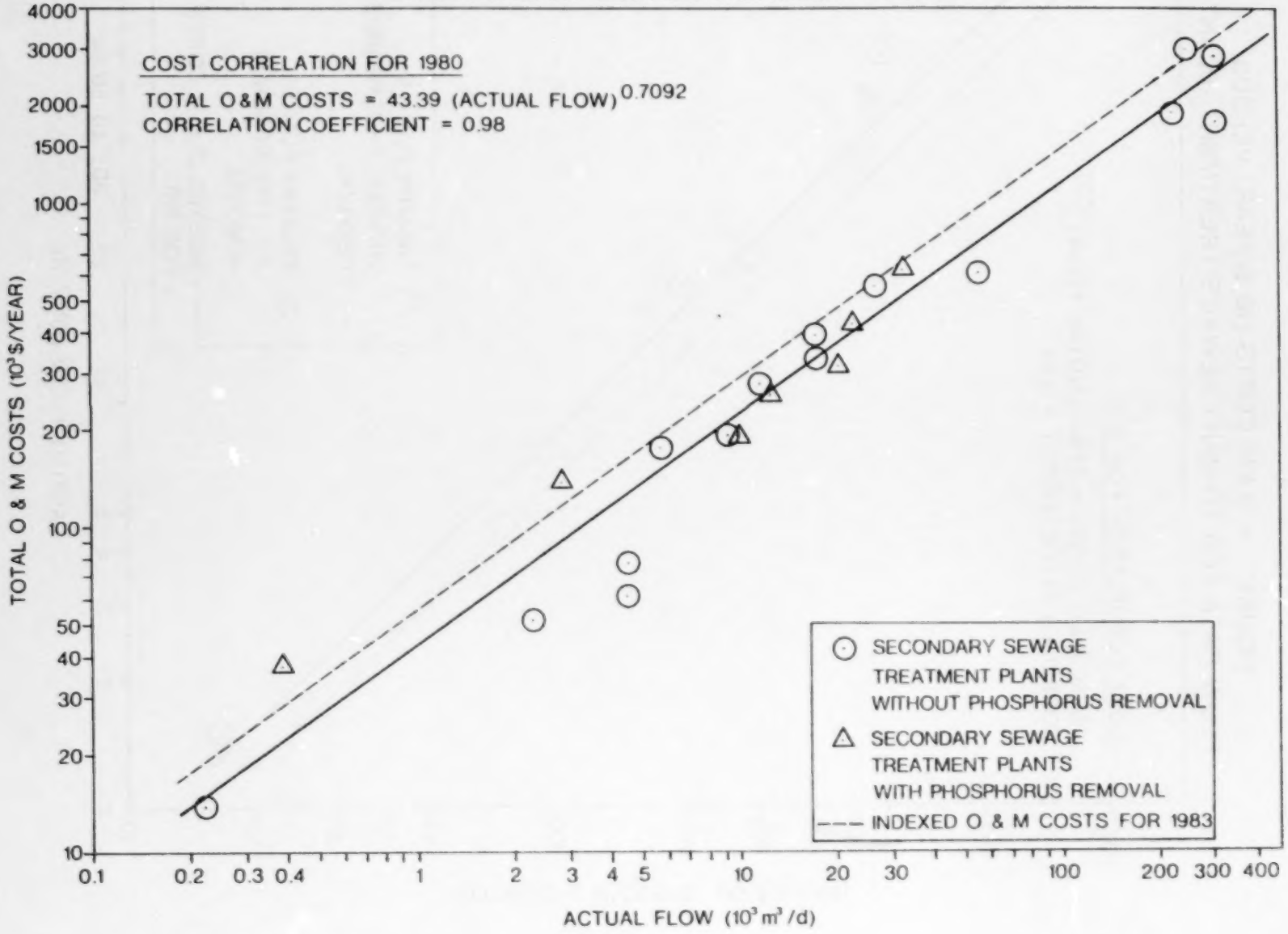

FIGURE 3 – O & M COSTS (10^3 $/YEAR) VERSUS FLOW RATE FOR AERATED LAGOONS

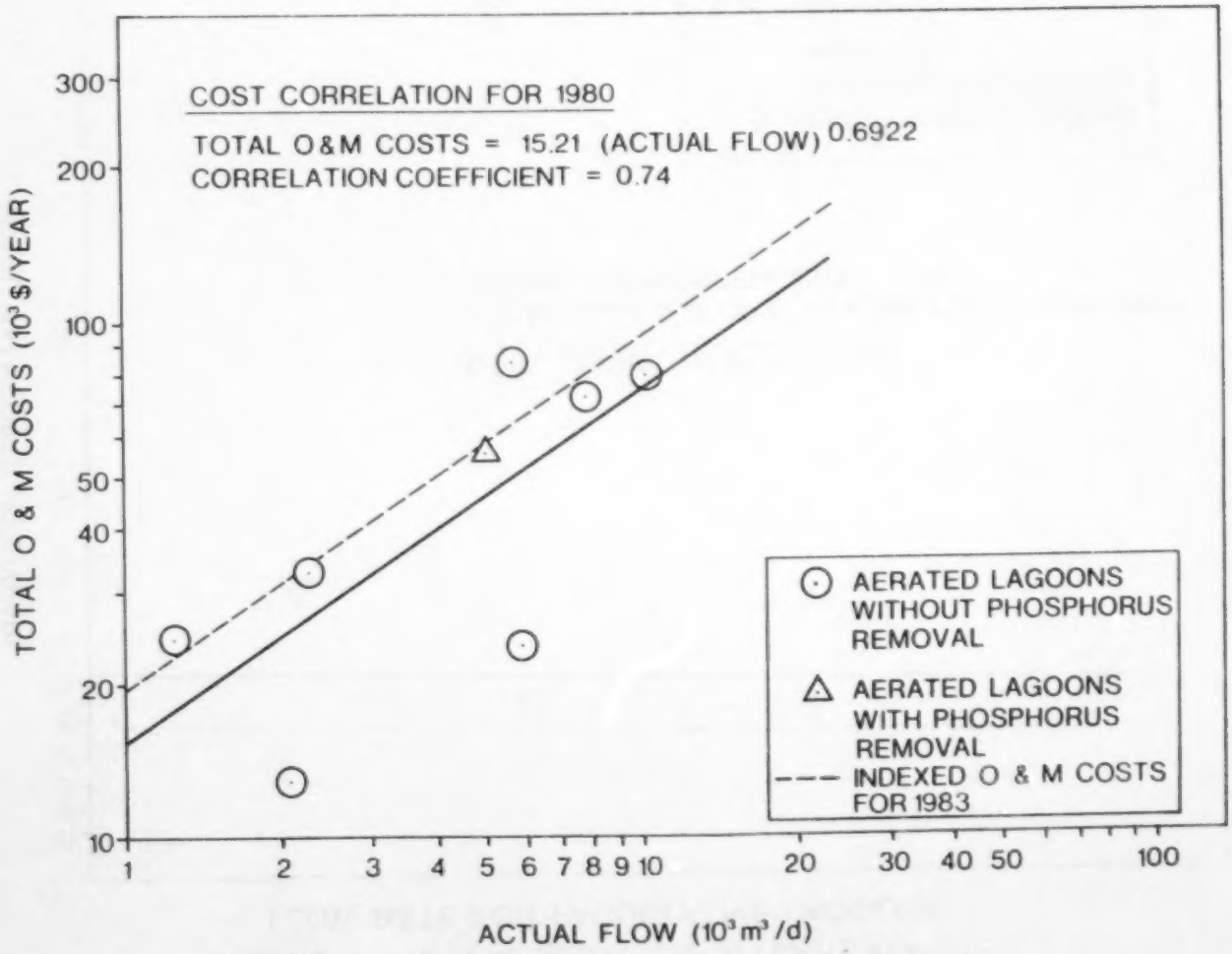

FIGURE 4 – O & M COSTS (10^3 $/YEAR) VERSUS FLOW RATE FOR FACULTATIVE LAGOONS

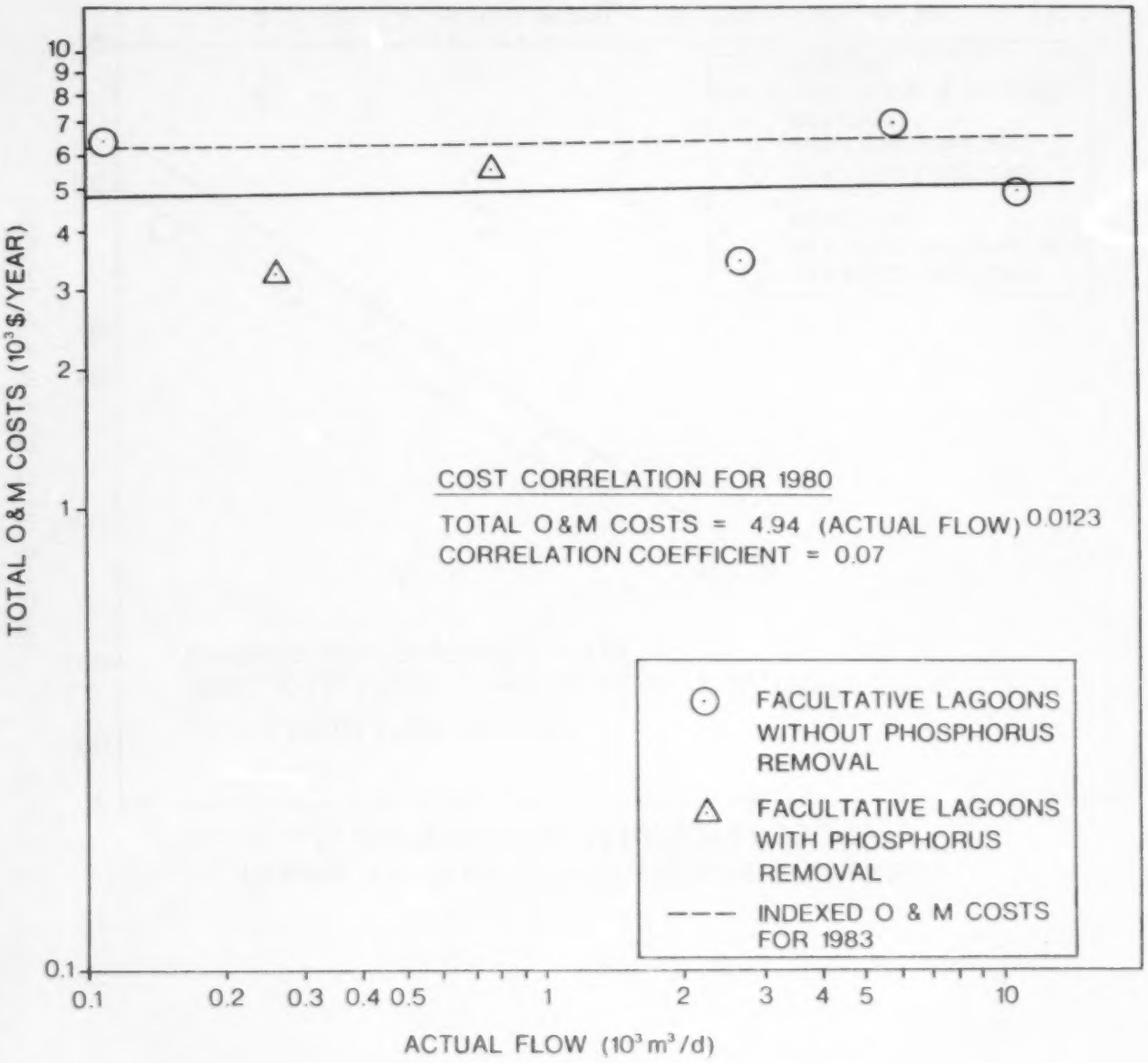

TABLE 5 HYDRAULIC LOADING CONDITIONS AT SURVEYED FACILITIES NUMBER OF PLANTS AND THEIR HYDRAULIC OPERATING CONDITIONS*

Plant Type	Hydraulic Underload (A/D<0.9)	Hydraulic Design Load (0.9 >A/D<1.1)	Hydraulic Overload (A/D >1.1)
Primary	5 (63)	1 (12)	2 (25)
Secondary	13 (59)	7 (32)	2 (9)
Aerated lagoon	4 (50)	1 (12)	3 (38)
Facultative lagoon	3 (43)	1 (14)	3 (43)
Totals	25 (56)	10 (22)	10 (22)

* Numbers in brackets represent the percentage of surveyed plant-types within a hydraulic operating category.

the National Inventory, revealed that of these facilities, design flow and actual flow information was available on 52 primary, 331 secondary, 68 aerated lagoon and 191 facultative lagoon facilities (Mundat, 1983). Seventy-one percent of all facilities were being operated at less than 90% of their design flow, 14% were operating within 10% of their design flow, and the remainder were in an overload state. For secondary plants the figures were 73%, 12%, and 15% for underloaded, design and overloaded hydraulic conditions respectively. Thus, while the numbers for this O & M survey do not coincide with National Inventory information, the trend toward underloaded conditions appears to be valid.

The impact of hydraulic loading conditions on operational costs at sewage treatment facilities may be examined by comparing Table 4 data with data in Table 6. The average cost for operating an activated sludge plant, based on a 19-plant survey and disregarding plant capacities less than 1000 m^3/day, was \$54 per 1000 m^3 of wastewater treated (Table 4). Costs associated with 6 plants in this same survey, but operating at design hydraulic conditions, were \$46 per 1000 m^3 (Table 6). Eleven of the plants were hydraulically underloaded at the time of the survey and were costing an average of \$60 per 1000 m^3 to operate; two plants in a hydraulically overloaded condition were costing \$46 per 1000 m^3. From these data it is apparent that plants operating at less than their design capacity have higher unit operating costs than plants treating wastes at or near design flows. Cost data on primary plants and lagoons are quite limited and trends are not so obvious. For example, the survey showed that the average cost for primary plant operation was \$44 per 1000 m^3 of sewage treated (Table 4). Table 6 indicates that these

costs for primary treatment are skewed to the hydraulic overload condition, in contrast to cost information for secondary plants. The raw data in Appendix A indicate that the two primary plants in the overload condition also provide phosphorus removal. This additional process may influence an increase in operational costs compared to costs of other primary plants in the same size category and without phosphorus removal processes. (The following subsection on component costs will examine this aspect of plant operation in more detail.) Aerated lagoon cost trends for underloaded versus overloaded facilities are consistent with the information on secondary plants in Table 6.

TABLE 6 AVERAGE COST PER 1000 m^3 TREATED BY OPERATIONAL CAPACITY ($/1000 m^3)

Ratio of Actual Flow to Design Flow	Level of Treatment		Lagoons	
	Primary	Secondary	Aerated	Facultative
A/D <0.9	40 (n=5)	60 (n=11)	31 (n=4)	-
0.9 <A/D <1.10	31 (n=1)	46 (n=6)	54 (n=1)	3 (n=1)
A/D >1.10	61 (n=2)	46 (n=2)	21 (n=3)	2 (n=2)

4.3 Component Costs

The analysis of total O & M costs on the basis of five budgetory categories is presented in Tables 7, 8, 9 and 10. Electrical, personnel, sludge handling, chemical and administration and miscellaneous cost components are examined according to process-type and flow range and are defined as being a percentage of the total annual O & M cost. Data presented in these tables are averages. Definitions of the cost categories are as outlined in section 3 of this report.

From the tables it is clear that personnel costs are the major fraction of operating expense for all sizes of primary and secondary plants and facultative lagoons. Typically, wages and benefits for operating and supervisory personnel accounted for 40 to 50 percent of the total operational cost. On the other hand, aerated lagoon systems experienced personnel costs in the 20 to 40 percent range.

TABLE 7 COMPONENT O & M COSTS (% of total O & M) FOR PLANTS WITH ACTUAL FLOWS LESS THAN 1000 m^3/d

Level of Treatment	No. of Plants	Components Costs (% of Total O&M Costs)				
		Electrical	Personnel	Sludge	Chemical	Administrative
Primary	--	--	--	--	--	--
Secondary	2	22	54	2	5	16
Aerated Lagoons	1	41	23	0	0	35
Facultative Lagoons	4	0	47	0	35	18

TABLE 8 COMPONENT O & M COSTS (% of total O & M) FOR PLANTS WITH ACTUAL FLOWS 1000 to 5000 m^3/d

Level of Treatment	No. of Plants	Components Costs (% of Total O&M Costs)				
		Electrical	Personnel	Sludge	Chemical	Administrative
Primary	2	10	57	0	4	32
Secondary	6	29	34	3	8	26
Aerated Lagoons	3	39	43	0	0	18
Facultative Lagoons	1	0	82	0	0	18

The cost for electrical power in a secondary sewage treatment operation ranged from 20 to 30 percent of the total annual expenditure. This compares to a 5 to 10 percent range for primary plants and a 40 to 45 percent range for aerated lagoons. It is interesting to note that power consumption, and the associated electrical costs, followed no discernible trend that could be associated with plant flow. The combined influence of plants operating at flow capacities outside their design range, as well as inconsistencies in operational characteristics among plants of the same process-type could be the principle reasons for the lack of correlation.

Costs associated with the treatment and disposal of sludges were reported for primary and secondary treatment facilities. Of the 9 primary plants surveyed, only 6

TABLE 9 COMPONENT O & M COSTS (% of total O & M) FOR PLANTS WITH ACTUAL FLOWS 5000 to 50 000 m^3/d

Level of Treatment	No. of Plants	Components Costs (% of Total O&M Cost)				
		Electrical	Personnel	Sludge	Chemical	Administrative
Primary	5	8	37	6	11	40
Secondary	11	18	48	9	6	20
Aerated Lagoons	5	44	23	0	12	21
Facultative Lagoons	2	12	24	0	2	63

TABLE 10 COMPONENT O & M COSTS (% of total O & M) FOR PLANTS WITH ACTUAL DAILY FLOWS GREATER THAN 50 000 m^3/d

Level of Treatment	No. of Plants	Components Costs (% of Total O&M Cost)				
		Electrical	Personnel	Sludge	Chemical	Administrative
Primary	2	5	50	13	14	19
Secondary	5	21	55	11	2	12
Aerated Lagoons	0	--	--	--	--	--
Facultative Lagoons	0	--	--	--	--	--

plants identified budgetary expenditures in this category. Five of those plants were medium-sized (i.e. 5000 to 50 000 m^3/d), and sludge processing represented an average of 8 percent of the total annual O & M budget. The sixth plant, with a flow of greater than 50 000 m^3/d and with a P-removal process, had a significantly higher budget expenditure for sludge processing. (ie. 27 percent). With secondary plants, the proportion of sludge handling costs ranged from 2 to 11 percent. Budgetary allocations to sludge handling increased with plant size, ie. in the 1000 m^3/d plants costing was a minimum at 2%, whereas in the large facilities (greater than 50 000 m^3/d) the average was 11%. Five of 24 secondary facilities did not report sludge costs.

The fraction of annual operating costs that may be attributed to the purchase of chemicals is presented in Tables 7 through 10. For secondary systems in the 5000 m^3/d to 50 000 m^3/d flow range and with P-removal processes, a 5-plant average for chemical costs was 10 percent of the total annual operating cost; 6 plants in this same flow range, but without P-removal processes had an average chemical cost of 2 percent. Two primary plants in the 5000 to 50 000 m^3/d flow range with P-removal utilized an average of 26 percent of their operating budget for chemical purchase; two similar-sized primary plants without P-removal had chemical costs that averaged 2% of their operating expenditures. Three small facultative lagoons employed chemicals, presumably for disinfection and/or P-removal purposes. The costs represented a significant portion (35%) of the total operating budget.

The budget category "Administrative and Miscellaneous Costs" showed that in general the fractional cost decreased as plant size increased.

4.4 Pollutant Removal Costs

Operating costs are analyzed on the basis of BOD, SS and P removals at surveyed plants and presented in Tables 11, 12 and 13.

In Table 11, costs associated with BOD removal are shown for primary, secondary and lagoon facilities. Primary plants experience high unit costs for BOD removal, as compared to the secondary plants and lagoon processes. Although the data base for primary plants is small, the results of this analysis appear quite reasonable. Primary treatment processes are designed and operated principally for the removal of solids. Any BOD removal that occurs as a result of this process is a function of the solids association.

Secondary plants exhibit the next highest average BOD removal costs, followed by lagoon facilities. Again, these relative costs may be expected given the greater complexity of secondary facilities, (and thus operating requirements), over lagoon systems.

Table 12 presents pollutant removal costs as they relate to suspended solids. These data illustrate a similar trend as seen in Table 11. Disregarding plant size, SS removal appears to be affected in a least costly manner via lagoon systems. Primary facilities represent the highest operational costs with respect to removal of this pollutant, followed closely by secondary facilities. Secondary plants in the 5000 to 50 000 m^3/d flow range are indicated as the most expensive facilities to operate for SS removal. A larger sampling of plants in the various flow ranges is required to confirm these results.

TABLE 11 AVERAGE COST PER Kg BOD REMOVED ($/Kg BOD removed)

Flow Category (m^3/d)	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	4.00 (n=1)	-	0.18 (n=2)
1000-5000	0.54 (n=2)	0.50 (n=3)	0.12 (n=3)	0.05 (n=1)
5000-50 000	0.61 (n=4)	0.47 (n=11)	0.23 (n=5)	0.13 (n=1)
> 50 000	0.53 (n=2)	0.20 (n=5)	-	-
All plants*	0.57 (n=8)	0.40 (n=19)	0.19 (n=8)	0.09 (n=2)

*Plants < 1000 m^3/d excluded.
n = number of plants included in calculation of average.

TABLE 12 AVERAGE COST PER Kg SS REMOVED ($/Kg SS removed)

Flow Category	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	3.00 (n=1)	-	0.17 (n=2)
1000-5000	0.37 (n=1)	0.28 (n=3)	0.30 (n=3)	0.07 (n=1)
5000-50 000	0.31 (n=4)	0.44 (n=9)	0.10 (n=3)	0.09 (n=1)
> 50 000	0.36 (n=2)	0.14 (n=5)	-	-
All plants*	0.33 (n=7)	0.32 (n=17)	0.20 (n=6)	0.08 (n=2)

*Plants < 1000 m^3/d excluded.
n = number of plants included in calculation average.

Table 13 summarizes average costs for P-removal at the various treatment facilities. No distinction can be made between plants with P-removal processes and plants where P-removal occurs as a function of solids removal or biological processes. Aerated lagoons have the highest average cost per Kg P removed ($23) followed by primary plants ($20), secondary plants ($16), and facultative lagoons ($2).

TABLE 13 AVERAGE COST PER Kg P REMOVED ($/Kg P removed)

Flow Category	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	84 (n=1)	-	5 (n=2)
1000-5000	20 (n=1)	14 (n=2)	29 (n=2)	1 (n=1)
5000-50 000	24 (n=2)	22 (n=6)	17 (n=2)	2 (n=1)
> 50 000	16 (n=2)	8 (n=4)	-	-
All plants*	20 (n=5)	16 (n=12)	23 (n=4)	2 (n=2)

*Plants < 1000 m^3/d excluded.
n = number of plants included in calculation of averages.

TABLE 14 AVERAGE COST PER CAPITA ($/capita/annum)

Flow Category (m^3/d)	Primary	Secondary	Aerated Lagoons	Facultative Lagoons
< 1000	-	45 (n=2)	-	13 (n=3)
1000-5000	9 (n=2)	11 (n=6)	11 (n=2)	1 (n=1)
5000-50 000	9 (n=4)	11 (n=11)	7 (n=5)	1 (n=2)
> 50 000	10 (n=2)	7 (n=5)	-	-
All plants*	9 (n=8)	10 (n=22)	8 (n=7)	1 (n=3)

*Plants < 1000 m^3/d excluded.
n = number of plants included in calculation of averages.

4.5 Per Capita Operating Costs

Table 14 presents average costs per capita for operating various types of treatment processes at various flow ratings. In general, secondary plants, with the most complex treatment processes, are presented as the most expensive to operate on a per capita basis at $10.00. Primary plants at $9.00 per capita, aerated lagoons at $8.00 per

capita, and facultative lagoons at $1 per capita follow secondary plants in this analysis. Further, on a per capita basis, the smaller plants appear to be more costly to operate than larger plants of the same process type. The exception to this trend is the primary plant category. Per capita costs for primary plants were $9 and $10 for the plants surveyed. A larger sample group should be surveyed in order to verify these results.

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APPENDIX A

Raw Data on Wastewater Treatment Plants

TABLE A.1 TREATMENT PLANTS LISTED BY LEVEL OF TREATMENT

Plant No.	Region	Phosphorus Removal	Design Flow 10^3 m^3/d	Actual Flow 10^3 m^3/d	% Design Flow	Total Annual O & M Costs $/1000 m^3 Design Flow	$/1000 m^3 Actual Flow	10^3 $/year
Primary Treatment Plants								
14	C	--	1.64	1.50	91	28.00	30.62	16.76
16	W	--	5.16	4.55	88	40.58	46.02	76.43
13	E	--	22.72	16.36	72	24.32	33.77	201.7
4	C	Yes	13.64	18.15	133	54.96	41.30	273.6
34	W	--	27.28	19.55	72	29.07	40.56	289.4
19	C	Yes	36.37	46.38	128	41.24	32.33	547.3
3	W	--	90.92	59.1	65	17.60	27.08	584.2
37	C	Yes	109.11	97.29	89	48.96	56.89	1949
11*	E	--	5.71	--	--	12.72	--	26.51
Secondary Treatment Plants								
53	C	--	0.45	0.22	49	86.54	175.99	14.13
1	C	Yes	0.50	0.39	78	209.14	268.13	38.17
42	W	--	2.29	2.30	100	63.48	63.20	53.56
41	C	Yes	3.64	2.86	79	106.55	135.61	141.6
45	W	--	2.95	4.54	150	57.45	37.33	61.86
47	C	--	6.82	4.55	67	31.76	47.61	79.07
38	W	--	7.00	5.75	82	70.73	86.11	180.7
6	E	--	9.46	9.46	100	56.38	56.38	194.7
36	W	Yes	8.18	9.72	119	65.55	55.16	195.7
39	E	--	13.63	11.73	86	56.16	65.26	279.4
9	C	Yes	13.64	12.55	92	52.27	56.81	260.2
52	W	--	22.73	17.25	76	40.32	53.13	334.5
44	E	--	22.72	17.41	76.6	47.86	62.46	396.9
26	C	Yes	27.28	20.52	75	32.15	42.75	320.2
31	C	Yes	29.55	22.65	77	40.09	52.31	432.5
40	W	--	29.51	26.5	90	51.99	57.90	565.9
17	C	Yes	61.37	32.51	53	28.18	53.20	631.3
50	C	--	68.19	56.01	82	25.00	30.44	622.3
28	W	--	250.00	225	90	21.34	23.71	1947
20	C	--	409.15	245.58	60	20.36	33.92	3040
29	W	--	313.26	302.73	96.6	25.43	26.32	2958
12	W	--	295.1	303.81	103	17.00	16.51	1831
43*	E	--	1.14	--	--	46.17	--	19.71
21*	E	--	2.27	--	--	24.06	--	19.89
25*	E	--	7.56	--	--	--	--	--
Aerated Lagoons								
8	C	--	1.27	1.25	98	53.36	54.22	24.76
48	C	--	5.46	2.07	38	6.48	17.19	12.92
27	E	--	13.57	2.27	23	6.72	40.17	33.28
30	C	Yes	4.54	5.06	111	34.17	30.66	56.63
51	E	--	11.35	5.68	50	20.48	40.92	84.84
22	W	--	4.54	5.86	130	14.41	11.17	23.89
23	W	--	10.28	7.88	80	19.39	25.29	72.74
5	W	--	6.82	10.23	150	32.07	21.38	79.83
33*	E	--	0.57	--	--	32.51	--	6.76
Facultative Lagoons								
10	W	--	0.07	0.11	160	255.95	162.88	6.54
15	C	Yes	0.73	0.26	36	12.33	34.62	3.29
35	C	Yes	0.98	0.78	80	15.69	19.72	5.61
49	C	--	2.39	2.72	114	3.99	3.51	3.48
32	W	--	6.36	5.91	93	3.52	3.25	7.01
18	E	--	0.73	11.36	1600	18.83	1.21	5.02
2*	E	--	0.20	--	--	--	--	--
46*	E	--	0.32	--	--	4.04	--	0.47
7*	W	--	3.64	1.59	44	--	--	--

*Plants with Incomplete Data

TABLE A.2 TREATMENT PLANTS AND THEIR COMPONENT COSTS

Plant	Region	Pop. Served 10^3	Electrical Costs $/1000 m³ Actual Flow	Electrical Costs % Total	Personnel Costs $/1000 m³ Actual Flow	Personnel Costs % Total	Sludge Costs $/1000 m³ Actual Flow	Sludge Costs % Total	Chemical Costs $/1000 m³ Actual Flow	Chemical Costs % Total	Additional Costs $/1000 m³ Actual Flow	Additional Costs % Total
Primary Treatment Plants												
14	C	2.2	3.20	10.5	20.84	68.1	0.0	0.0	0.0	0.0	6.58	21.5
16	W	8.0	4.19	9.1	20.81	45.2	0.0	0.0	1.81	3.9	19.21	41.7
13	E	30.0	2.38	7.0	18.15	53.7	0.0	0.0	0.0	0.0	13.24	39.2
4	C	28.6	3.58	8.7	16.58	40.1	4.88	11.8	14.65	35.5	1.60	3.9
34	W	40.0	4.46	11.0	20.74	51.1	0.60	1.5	0.0	0.0	14.76	36.4
19	C	49.0	0.74	2.3	8.65	26.8	1.82	5.6	5.20	16.1	15.93	49.3
3	W	135.7	1.29	4.8	17.79	65.7	0.0	0.0	2.27	8.4	5.73	21.2
37	C	130.0	2.68	4.9	18.82	34.3	14.52	26.5	10.25	18.7	8.61	15.7
11[1]	E	4.0	1.14[2]	9.0	1.84[2]	14.5	0.0[2]	0.0	0.53[2]	4.2	9.21[2]	72.4
Secondary Treatment Plants												
53	C	0.3	55.73	31.7	89.21	50.7	0.00	0.0	3.66	2.1	27.40	15.6
1	C	0.9	32.30	12.0	155.31	57.9	12.32	4.6	22.47	8.4	45.73	17.1
42	W	5.7	26.13	41.3	22.15	35.0	0.00	0.0	0.00	0.0	14.93	23.6
41	C	7.1	27.39	20.2	59.52	43.9	16.28	12.0	19.29	14.2	13.12	9.7
45	W	4.5	4.21	11.3	11.18	29.9	0.33	0.9	1.60	4.3	20.01	53.6
47	C	6.7	15.99	33.6	22.59	47.4	2.82	5.9	0.66	1.4	5.56	11.7
38	W	15.0	19.27	22.4	63.57	73.8	2.19	2.5	0.00	0.0	1.07	1.2
6	E	30.0	5.27	9.3	23.28	41.3	4.94	8.8	2.03	3.6	20.85	37.0
36	W	22.0	5.46	9.9	33.44	60.6	1.67	3.0	1.86	3.4	12.72	23.1
39	E	23.0	15.46	23.7	21.67	33.2	1.51	2.3	2.29	3.5	24.33	37.3
9	C	32.0	6.69	11.8	21.58	38.0	12.58	22.1	5.71	10.1	10.26	18.1
52	W	50.0	16.87	31.8	28.00	52.7	0.00	0.0	1.20	2.3	7.05	13.3
44	E	41.4	19.09	30.6	21.78	34.9	14.84	23.8	0.52	0.8	6.23	10.0
26	C	26.5	5.65	13.2	20.86	48.8	7.25	17.0	5.88	13.8	3.10	7.3
31	C	45.0	6.71	12.8	28.40	54.3	0.25	0.5	6.36	12.2	10.58	20.2
40	W	21.0	9.90	17.1	36.67	63.3	0.82	1.4	0.83	1.4	9.67	16.7
17	C	59.7	7.35	13.8	16.83	31.6	8.02	15.5	4.83	9.1	16.16	30.4
50	C	85.0	10.75	33.3	11.05	36.3	5.11	16.8	0.67	2.2	2.85	9.4
28	W	365.0	5.20	21.9	12.01	50.7	3.27	13.8	0.86	3.6	2.37	10.0
20	C	360.0	4.58	13.5	19.31	56.9	3.77	11.1	0.36	1.1	5.90	17.4
29	W	400.0	7.07	15.5	17.76	67.5	1.44	5.5	0.27	1.0	2.79	10.6
12	W	425.2	2.90	17.6	10.19	61.7	1.10	6.7	0.02	0.1	2.30	13.9
43	E[1]	2.5	20.42[2]	44.2	12.65[2]	27.4	0.00[2]	0.0	8.41[2]	18.2	4.69[2]	10.2
21	E[1]	3.2	5.48[2]	22.8	5.44[2]	22.7	0.00[2]	0.0	2.40[2]	10.0	10.68[2]	44.5
25	E[1]	75.8	--	--	98.94[2]	--	0.00[2]	0.0	0.00[2]	--	2.17[2]	--
Aerated Lagoons												
8	C	1.4	27.51	50.7	22.01	40.6	0.0	0.0	0.0	0.0	4.69	8.6
48	C	3.8	0.21	1.2	13.63	79.7	0.0	0.0	0.0	0.0	3.26	19.1
27	E	0.2	26.21	65.2	3.95	9.8	0.0	0.0	0.0	0.0	10.01	24.9
30	C	5.0	8.98	29.3	11.03	36.0	0.0	0.0	6.78	22.1	3.87	12.6
51	E	6.5	12.58	30.7	17.10	41.8	0.0	0.0	5.16	12.6	6.09	14.9
22	W	9.3	3.88	32.6	1.62	14.5	0.0	0.0	0.47	4.2	3.20	28.6
23	W	30.0	15.83	62.6	4.32	17.9	0.0	0.0	0.0	0.0	4.94	19.5
5	W	13.5	9.10	42.6	0.63	2.9	0.0	0.0	4.95	23.2	6.70	31.3
33	E[1]	1.4	13.41[2]	41.2	7.61[2]	23.4	0.0[2]	0.0	0.0[2]	0.0	11.49[2]	35.3
Facultative Lagoons												
10	W	0.2	0.0	0.0	68.74	42.2	0.0	0.0	25.89	15.9	68.24	41.9
15	C	0.8	0.0	0.0	9.65	27.9	0.0	0.0	18.02	52.1	6.95	20.1
35	C	1.7	0.0	0.0	3.60	18.3	0.0	0.0	14.01	71.0	2.11	10.7
49	C	6.3	0.0	0.0	2.88	82.1	0.0	0.0	0.0	0.0	0.62	17.7
32	W	14.0	0.0	0.0	0.75	23.1	0.0	0.0	0.0	0.0	2.50	76.9
18	E	2.8	0.28	23.1	0.30	24.8	0.0	0.0	0.04	3.3	0.60	49.6
2	E[1]	0.9	0.0[2]	--	--	--	0.0[2]	--	0.0[2]	--	2.74[2]	--
46	E[1]	0.9	0.0[2]	0.0	4.04[2]	100	0.0[2]	0.0	0.0[2]	0.0	0.0[2]	0.0
7	W	5.1	--	--	0.87	--	0.0		0.0	--	0.65	--

1 Design Flow Only (10^3 m^3/d)
2 $/1000 m^3 Design Flow